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Adaptive Instructional Systems (AIS)

Final Report

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13. ABSTRACT *(Maximum 200 words)*

Adaptive Instructional Systems are those systems which guide the students instruction based on the student's performance and current abilities. This report describes an Adaptive Instructional System designed on using Conceptual Graphs to maintain an internal concept of both the student and the instructor. The graphs are shown as being capable of monitoring and guiding the instruction adaptively.

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Adaptive Instructional System (AIS)

Overview

Introduction

Research Perspective

Warfare in the middle of this century was based on simpler technology. In past conflicts, the war fighters used limited local data. The combat was direct and they learned to use their combat systems by rote so that they could function effectively even when highly stressed in a combat environment. These combatants also needed highly developed individual perceptual motor skills for controlling and aiming the weapon systems in use at mid-century. That weapon technology has been extended by information technology, which brings a broader scope of the battle to the war fighter earlier in the conflict. This permits, and requires, the war fighter to manage the presented information and to think about the situation and courses of action required by a detailed opponent picture. The breadth and depth of information requires not only higher level reasoning in the individuals, but also effective coordination of war fighters on a larger scale than with traditional crew served weapon systems.

While technology was revolutionizing information usage in war, the high cost of personnel, and the limited budgets in the latter part of the century, decreased the resources available to train the war fighters. These reductions in resources occurred at a time when large numbers of limited intervention missions were assigned to the services. This further stressed the remaining resources, so that training the advanced war fighter suffered.

Even when training resources can be found, traditional training methods are deficient for the advanced war fighter's training needs. A major shortcoming is the "mass production" concept behind military training. With everyone in lock step, the slower students set the pace for everyone. Tailored instruction, which pushes faster students through the training courses, could speed up training, but is very complex for a training staff to administer. Therefore, only small groups can capitalize on this approach. Small groups require more instructors, which is labor intensive. Tailored instruction appears to become infeasible for traditional training commands.

The solution is to look at how training is done, then invest in cost effective improvements to the training process. Intelligent computerized training systems offer an effective automated approach to training. The intelligent system approach must provide both mechanical skill training and knowledgeable tutoring in modern warfare for both individuals and groups. Further, automation must be adaptive, in order to tailor the training to individual students. While all levels of instruction should be addressed, the highest payoff may occur in basic instruction classes. Here large numbers of students and instructors mean the commitment of significant resources. Sufficient intelligence must be embedded in an intelligent trainer to relieve the instructors from basic instruction so that they can focus on the most demanding forms of instruction. By utilizing fewer instructors in these basic courses, the total administrative and planning costs for the instruction is lower and the initial investment cost can be repaid.

Developing a competent level of intelligence in a trainer requires the combining of a deep understanding of the instructional area, of learning psychology, and of student cognitive processes. Clearly, the development of conceptual models of the students, of instructional methods and of instructors is the key to this entire process. Therefore, the development of conceptual models is the central theme of this report.

Research Goals

The goals of this research are to develop an intelligent flight trainer design that can improve the quality and speed of training with reduced human intervention and supervision. Specifically the trainer must:

1) Adapt the instruction to fit the student's performance and the student's style of learning,

2) Within limits, identify and plan the student's instruction,

3) Provide pre-flight briefings, in-flight monitoring, and post-flight evaluation,

4) Utilize existing simulator hardware and software,

5) Provide the data extraction and storage to support experimentation on teaching and learning techniques,

6) Provide a path to learning systems that automatically learn to teach.

Research Issues

Although the overall goal of this effort is to develop an approach and a design for dynamically adaptive instructional system, which is sensitive to a student's learning style, learning rate, and overall strengths, the research is focused on specific issues. Three issues are identified and addressed as the first step to achieving this goal:

1) Can a conceptual model of a student's knowledge be defined and captured dynamically? Similarly, can the Instructor's knowledge and the pedagogical knowledge be modeled?

2) Can a computer model be developed which efficiently implements a student's, an Instructor's and pedagogical conceptual models?

3) Can a student's conceptual model be made to adapt as the student learns or changes behavior based on a knowledge of instructional methods and Instructors?

Research Team

Dr. David J. Skipper, Program Principal Investigator, Bevilacqua Research Corporation (BRC)

Dr. Skipper has more than 23 years experience in management and all aspects of the full life cycle for software engineering design and development. Dr. Skipper received his BS in Physics with Honors from the University of Texas at Arlington, in Arlington Texas and his Ph.D. in Physics from the University of Missouri in Rolla, Missouri. His experience includes embedded real time systems, telemetry systems and data reduction, expert systems, computer and network modeling, client server database design, computer user interfaces, and weapon system modeling. At BRC, Dr. Skipper developed intelligent software modules for models such as ITEMS and ModSAF using advanced techniques in artificial intelligence.

Dr. Skipper is also a Part Time Lecturer at the University of Alabama in Huntsville in the Computer Engineering Department; His teaching areas are data structures, and C/C++ programming.

Dr. Harry S. Delugach, The University of Alabama in Huntsville, University of Alabama – Huntsville (UAH)

Dr. Delugach is a tenured Associate Professor of Computer Science at the University of Alabama in Huntsville and an internationally renowned expert in conceptual modeling. His research interests are in the areas of software engineering, software requirements, object-oriented modeling, knowledge-based systems, conceptual graphs, computer science education. His formal education includes a Ph.D. in Computer Science, University of Virginia, Charlottesville. Dissertation Title: "A Multiple Viewed Approach to Software Requirements," an MS in Computer Science, University of Tennessee, Knoxville and a BA in Chemistry, Carleton College, Northfield, Minnesota. He has extensive professional experience ranging from teaching to computer operations and is widely published in the field of conceptual modeling.

Dr. Debra Evans, Cognitive and Behavioral Systems (CABS)

Dr. Debra C. Evans is the owner and founder of Cognitive and Behavioral Systems, which is a woman owned consulting firm dedicated to identifying and solving human performance problems for government and industry customers. Dr. Evans has over fifteen years of experience in applied human factors and ergonomics, training research, analysis, design, and production. Her research interest and training are in learning and cognitive processes. She has applied her knowledge and skills in these areas, as well as her extensive experience in experimental design and analysis, to solve human factors and training research application problems. Her formal education includes a BA from Carleton College, 1976, with an MA and Ph.D. in Experimental Psychology from University of California, Davis, 1978 and 1983 respectively. She has worked extensively with both commercial and government clients, in many different research areas relating to human performance issues, whether software, training, or ergonomic problems.

Additionally, Dr. Evans is a visiting lecturer in Human Factors and Human Information Processing at the University of Pittsburgh's School of Information Science.

Technical Approach

In past work, the BRC Team observed that intelligent training systems depended heavily on the development of a behavior model external to the trainer itself. The trainer maintained only a minimal semblance of an internal conceptual model. This profoundly limits the capabilities of adaptation schemes as well as limiting learning opportunities. It was hypothesized by the BRC Team that a detailed internal conceptual model set would lead to better adaptation as well as learning systems. the BRC Team has spent considerable effort examining conceptual models of intelligence and has developed tools, systems, and software based on complex conceptual models using novel technical advances based on Sowa's [1984] conceptual graphs.

Use of these insights and tools would appear to lead to significant advances in intelligent trainers. This overall approach, which is discussed in Section 2, is based on these key technical tasks:

1) Generating conceptual models of student, instructor and pedagogical knowledge,

2) Evaluation of student performance using conceptual models,

3) Adaptation of instructional conceptual models to induce changes in the student's conceptual model,

4) Implementation and utilization of the conceptual models in a computerized trainer for adapting subsequent instruction.

Significant Results

During the course of this study, the following key results were obtained:

1) Initial student conceptual models were created,

2) Initial instructor conceptual models were created,

3) Methods were identified to dynamically update a student's conceptual model,

4) Methods were identified to adapt the instructional conceptual models in response to the Student's behavior.

Document Structure

Section Descriptions

Section 2 covers the technical overview and trainer design concepts that resulted from this study. Section 3 covers the summary and the recommendations for future investigations.

Appendices

This report contains the following Appendix:

Appendix A Conceptual Model Demonstration.

Section

2

Technical Results

System Concept

Study Overview

Adaptation Description

Adaptation is a term that is sometimes ambiguous in various studies. In order to forestall that problem, this study utilized the view of adaptation described here. Figure 1 depicts the overall concept of adaptation used in this study. The concept requires some baseline of the desired "performance" from the student in the trainer. The student then interacts with the trainer. By some set of observations the student's "performance" is measured and compared to the

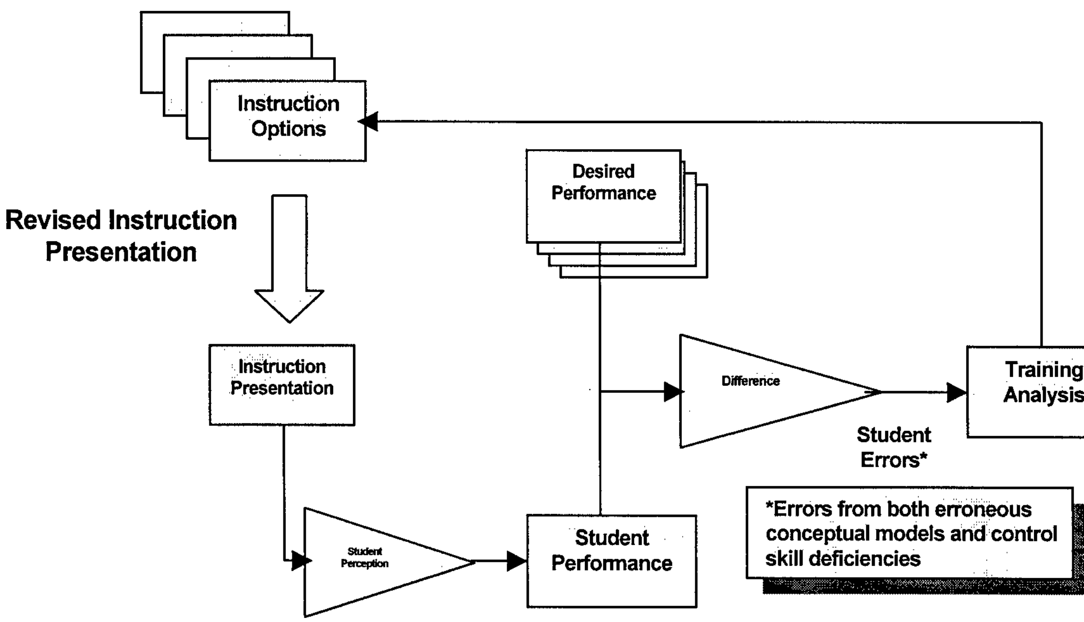

Figure 1 Adaptation

baseline "performance". The difference between these two measurements provides a basis for selecting the next interaction with the student. Clearly, this is a dynamic ongoing process with four key elements. The first key element is the definition of a baseline "performance". The second key is the observation of the student to determine the student's "performance". The third is the determination of the difference or errors in the two. The final key element is the decision process to select the next interaction.

The word "performance" is used here in a general sense. Not only is the student's immediate action set a measure of performance, but the student's concept set is a measure of what has been learned. Therefore when performance is referenced, both of these enter into the performance determination. Further, the student concept set can be viewed as including both working and long term memory. Consequently, the concept set consists of both working and long term concept sets, with, (potentially,) different performance evaluation approaches to each.

Previous Adaptive Trainer Work

The field of intelligent trainers is a relatively large one, with initial conceptual development beginning in the early 1980's. Consequently, rather than survey the field, representative examples are examined.

Over the last two decades, intelligent tutors have been developed to train personnel on may different types of tasks, from the operations of shipboard propulsion plants via graphical representions (Stevens, et. al, 1981) to medical diagnoses or LISP via rules (Clancey, 1983; Anderson & Reiser, 1985). Most of these tutors have used similar approaches to representing the student mental model—as a rule set, although they have frequently differed in pedagogical methods.

For example, STEAMER (Stevens, et. al, 1981) used a low fidelity simulation of a shipboard propulsion powerplant to present functional and operational concepts to naval personnel. Explanations were supplied to trainees based on the types of errors they made. Thus the student model consisted of a combination of an error or "bug" library and a set of rules for problem selection.

More recent tutors such as the LISP tutor developed by Anderson and his associates (1989, 1990) have used sets of production rules both to reflect the student model and to be the knowledge base to train. GUIDON, developed by Clancey (1983) used a similar approach for the training of medical diagnostic procedures.

Another approach to student modeling as seen in adaptive trainers is the comparison of the student's assumed conceptual model with a model of expert performance on the same task (see for example, Fath, 1987). However, in these trainers, usually a rule-based approach is used as well. The rule-based approach has a tendency to be most applicable to training situations that are deterministic and with well-constrained dynamics. There are no gradations of "rightness"or possibilities for multiple correct or incorrect performance paths for either the trainee or the expert.

Trainer Design Approach

In past work, the BRC Team observed that intelligent training systems depended on development of a behavior model external to the trainer itself. The trainer maintained only a semblance of an internal conceptual model. This profoundly limits the complexity of adaptation schemes as well as limiting learning opportunities. It was hypothesized by the BRC Team that a detailed internal conceptual model set would lead to better adaptation as well as learning systems. The BRC Team has spent considerable effort examining conceptual models of intelligence and has developed tools, systems, and software based on complex conceptual models using novel technical advances based on Sowa's [1984] conceptual graphs. Use of these insights and tools would appear to lead to significant advances in intelligent trainers. This overall approach is based on these key technical tasks:

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4) Implementation and utilization of the conceptual models in a computerized trainer for adapting subsequent instruction.

Student and Instructor Conceptual Models

In order to demonstrate the capability to develop conceptual models for students, the BRC Team participated in knowledge acquisition sessions at Ft Rucker on 14 April 2000, with a follow up session on 17 May 2000. Knowledgeable Instructors pilots were interviewed on student behavior and training students. These notes were translated into typical training scenarios. From these scenarios, basic student and instructor conceptual models were developed. The models were then manipulated as if in an actual trainer to demonstrate the most fundamental operation of the conceptual model based approach to trainer development. The entire process can be examined in more detail in Appendix A. This demonstrated the ability to capture and utilize initial conceptual models of students. There are additional details required for implementing a usable adaptive intelligent trainer. These are discussed later in this section.

Evaluating Performance with Conceptual Models

Three performance evaluation methods were found suitable for this trainer. The first is to monitor attribute values of key concepts within the conceptual model. This closely mimics the behavior of traditional trainers, making it possible to incorporate performance techniques from existing trainers. The second technique is to evaluate the graph structure itself. The topology and the existence of nodes and relations represent the conceptual model. Graph similarity measures of various types are available to measure the nearness of one conceptual graph to another. Future work will investigate the significance of using a given measure in a given situation. The third technique is the total uncertainty contained within a student's model. By observing the student and probing the student with key questions, an estimate of the regions in a model where the student has uncertainty in concepts or behaviors is available. By maintaining the student model and standard models, all appropriately normalized within a given belief system, the system can estimate performance based on residual uncertainty in the student's models.

Adapting Conceptual Models

As noted earlier, adaptation in the trainer means the selection of course material and interactions in response to the student's demonstrated abilities. Based on the differences determined in the previous section, a decision is made about the instruction to be presented. This is the first stage of adaptation. A conceptual graph decision component will be developed to handle this task based on standard knowledge engineering techniques. In a second level adaptation, this conceptual graph will adapt itself to select the training material based on perceived factors other than actual direct performance. Factors include error rates and fatigue factors, which may alter the relational basis and decision points within the graph.

Learning

Learning by the trainer is not a requirement of this study. However, by representing the student's conceptual models, both desired and actual, as conceptual graph structures, the progress of learning in a student can be established by the graph structures sequenced in time. By studying the evolution of the conceptual models of various students, as directed by the instructor model's graph based decisions, it is expected that experimenters may be able to identify key points in the student's graph formulation. These points drive changes in the instructor model's graph structure. This set of conceptual graph sequences in the instructor represents the sequence of learning in the instructor model. Pursuing the conceptual graph approach will permit identification of a set of instructional approaches that a trainer must develop. While this is not yet self learning it represents a means to prepare an instructor to learn new methods on its own. In the longer term, an encyclopedia of instructional techniques could be developed to permit the instructor model to experiment with best approaches for students.

Our example models and concepts were manually elicited through conceptual analysis of interviews involving human pilot instructors. A key feature of self-learning is the capability to develop new concepts without human intervention. One technique for establishing new concepts is formal concept analysis (FCA) as described by Ganter and Wille [1999] and others. Formal concept analysis permits collections of attribute values to organize themselves into clusters, establishing related sets as new concepts. We will be exploring the use of FCA in expanding the base set of manually acquired mental models.

Implementing Conceptual Models

The implementation process contains several challenges. First, efficient graph algorithms must be implemented to create the student's conceptual. Skipper [1998] has accomplished this for basic graphs in a previous trainer test. The next problem will be to implement interfaces to some existing trainer equipment to sense the trainer and the student. The design summarized in the Design Overview Section contains a presentation module. This module will be the interface module to a selected simulation and it will have to be customized for each simulator in which this is to be embedded.. The last potential problem is to exchange student conceptual models with other researchers for study or evaluation and with other trainers for collaborative training development. Fortunately, conceptual graphs have an ANSI standard format, Conceptual Graph Interchange Format (CGIF), for just that purpose.

Findings

This study began by identifying the issues that were critical to an advanced adaptive trainer development. In summary, these were the development and maintenance of key conceptual models, evaluation of the student's "performance," adapting the course of instruction to maximize the student's performance, and efficient implementation of these models. During the course of this study, the following key results were obtained:

1) Initial Student conceptual models were created to demonstrate model creation (Appendix A),

2) Initial Instructor sequence conceptual models were created (Appendix A),

3) Methods were identified to dynamically update and evaluate a student's conceptual model, specifically

   - Performance evaluated by values,
   - Graph similarities,
   - Certainty levels.

4) Methods were identified to adapt the instructional conceptual models in response to the Student's behavior, such as

   - Fixed selection of instructional graph templates
   - Adaptive selection of instructional graph templates

These were used to develop the top-level adaptive trainer design presented in the following section.

Design Overview

Figure 2 shows a block diagram of an adaptive intelligent flight trainer. There are six major components in the system. The first is the presentation manager. Because this system is a software system designed for insertion into an existing trainer, the Presentation Manager serves as the interface module to whatever trainer system is selected as the host system. It translates the sequences of instructional concepts requested by the instructor into actual simulated sequences by invoking the host simulator system. It also maintains a Student Observer module that utilizes

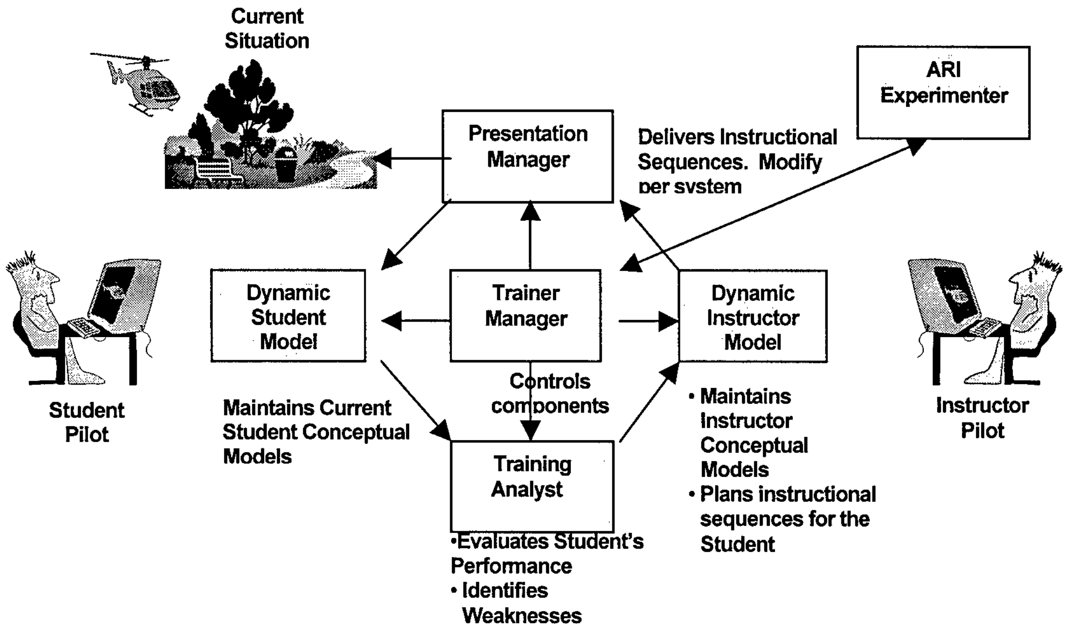

Figure 2 System design

the facilities of the host system to collect activity and performance information on the student. These and other key components are discussed in the following sections.

Instructor Model

The Instructor Model will supply training to a student using the pedagogic methods that are the most effective for that individual. These sequences and methods will be modeled and retained as conceptual graphs. However, available methods will be those that are supported by empirical and theoretical work on learning and transfer of training.

For training primary helicopter tasks, the instructor model will stimulate a flight simulation capability as a primary mode for exercise presentation. However, the Instructor model will support several pedagogic approaches, including:

- Task preview, in the appropriate modality for the student's learning style
- Step and procedure cueing, appropriate to the student's learning style

- Immediate corrective feedback
- Task performance aids
- Probe questions
- Positively reinforcing statements
- Task cessation and restart when a pre-set error limit is reached
- Changes in performance requirements as the student becomes more proficient
- Part to whole training
- Whole to part training, which is a strategy that is frequently effective with visual-spatial learners
- Discourse referral, in which the on-line instructor refers back to previous guidance or discussion

These approaches can be described and illustrated as follows:

Task Preview: Human instructors, when interacting with novices, frequently describe the task that is to be performed in a step-wise fashion to allow the student to prepare him/herself for the task, and to guide the performance of the task. This guidance has been referred to as "advance organizers" in the literature (Ausuble, 1960). Advance organizers supply the student with a mechanism by which he/she can begin to identify the relationships among new knowledge and skill elements with those that have been previously acquired. This mode of presentation is appropriate for auditory learners (Silverman, 1995). However, for those students whose preferred learning style is not auditory, other modes need to be used to supplement the verbal task/step description to supply appropriate organization (Silverman, 1995). Therefore for the adaptive learning system, during Task Preview, the "instructor" will verbally explain the current task or task step to the student. For students who are auditory learners, the information will be presented auditorially. For those students who are visual-spatial learners, in addition to the auditory presentation, a visual simulation of the helicopter's flight path and the views the student will have will be presented simultaneously to the auditory presentation. For kinesthetic learners, the system will request them to place their hands and feet on the controls. The system, then while presenting the auditory preview, will move the controls in a way to simulate the kinesthetic input that the students would have during the task or task step.

Cueing: One important role that a human instructor performs for a novice is to point significant task or step features and their importance is task performance immediately prior to their actual use. The act of cueing informs the student of when a signal or event to be detected is to occur. It draws the student's attention to the signal so that the student may analyze it and act if necessary (Patrick, 1992). Thus, the system will indicate auditorially, and if possible, visually the location of the information that is to be attended to or the control that is to be manipulated. In this way, the information will be made available to the student model as it is needed and therefore will be more likely to be acted upon.

Corrective Feedback: If the student does not perform a maneuver correctly, then the system will point out, based on the assumed mental model of the student as compared to the standard for performance, where the error has been made, the potential reason for the error, and the steps to correct the error. This, again, is a method frequently used by human instructors to shape student behavior. (Fox, 1993a; Moore, 1993) (See Appendix A)

Performance Aids: Performance aids are frequently used to support decision making in situations in which decisions are based on complex, dynamic information (Vazquez-Abad & Winer, 1992). Flying a helicopter is such an environment. Helicopters do have instrumentation that serves as performance aids. However, the use of these aids may be too difficult for a novice to initially integrate into his/her on-going mental model to support performance. Therefore, we will perform research to determine if there is some other type of display that more information in a way that is more useful to novices as they learn to maneuver the helicopter.

Probe Questions: One way that human tutors gain information concerning a student's thought processes is to ask questions (Fox, 1993b). This process can serve multiple functions. First, the answer to a question can indicate whether or not a trainee has available in working memory a piece of information. If the student does not have that information, the probe question can serve as cue to the student to either retrieve the information or if it a question focusing on an observable, make the needed observation. Additionally, the way in which a student answers a question can indicate changes in stress. For example, if the student answers quickly and tersely, and in a vocal level that is at a higher decibel and/or frequency level than is normal, then it is possible that the student's stress level is increasing. As stress level decreases, there is likely to be a reduction in amount of information available in and to working memory. Additionally, the student will begin to "tunnel' both perceptually and cognitively.

Positive Reinforcement: It is a well-established principle that supplying positive feedback indicates to a student what he/she is doing correctly within a task Additionally, according to flight instructors interviewed during the development of this description, supplying positive feedback aids in fostering a high level of self esteem in the student. The instructors have noted that when a student feels as though he or she is accomplishing tasks current satisfactorily, they feel more confident with regard to subsequent task performance. If the student feels confident in their performance, they are less likely to suffer from the negative impact of stress upon cognition and behavior.

Task Restart: If a student errs from the task by a defined amount, the system will require the student to restart the task. This approach will help to ensure that students do not learn incorrect procedures. If students learn and rehearse for any length of time incorrect actions during training, there is a chance these inappropriate actions may transfer to the actual flight setting, rather than the correct ones. Use of the these inappropriate behaviors could potentially have catastrophic results. However, it should be pointed out, that later in the training, it may be useful to train students in ways to correct error situations.

What is defined as unacceptable will vary, given the student's experience level on the task or on similar ones, such that the standards will be more lenient initially, and will become more strict as the student gains more experience. This is very similar to the way flight instructors shape correct performance of each student. The system will supply the student will corrective feedback based on the type of error detected and the assumed mental model of the student. Positive feedback in the form of information of correctly performed task steps will also be supplied. Once feedback has been supplied, the student will be allowed to restart the exercise.

Part to Whole Training: Many training and instructional systems present tasks in a step-wise fashion, starting with teaching each step or part of the task, then training combined sets of steps, and then finally all steps together. This method of presentation is suitable for certain types of learners (auditory, sequential learners) or certain types of tasks, especially those that require one to follow a procedural sequence (Fisk, 1987; Mane, 1984). Many helicopter maneuver tasks can be broken down into their constituent elements, and that is what flight line instructors do as they train the tasks. However, there may be certain aspects of the task that cannot be broken down and must be trained as a whole, but within a simplified situation. It is expected that students who are interacting with the system early in the training cycle will require more simplified exercises than they will require later in the cycle.

Whole to Part Training: Another approach to the presentation of tasks to be performed is to present the task as a whole, and let the student attempt to perform the task. This approach often is used in situations in which it is difficult to break a task down into constituent sub-tasks or for use with students who tend to see task elements as inter-related (Wightman & Lintern, 1985; Silverman, 1995). If the student has difficulties, based on the observation of performance and then the assumption of the current mental model, the system will focus on the specific task aspects that seem to be the locus of the incorrect performance. It should be pointed out that whole-to-part learning is frequently a better approach for visual-spatial learners than is a more sequential one such as part-to-whole training tends to be (Silverman, 1995). Additionally, since flying a helicopter has many task elements that must be performed simultaneously, a student needs to have an understanding of those task elements in their integrated form early in the learning cycle in order to perform in an acceptable way on subsequent tasks. As mentioned previously, in the event that it is not feasible to break a task or part of a task into constituent elements, the system will present a simplified version of the integrated task or step.

Discourse Referral: Discourse referral is a critical feature of human discourse, and it is widely used by human tutors (Moore, 1993). Human tutors frequently refer back to information previously presented to students in order to bring that information and associated information into working memory of the student. Such a strategy will be implemented within the Instructor of the adaptive system. In cases in which the student is not performing as expected and there is a record of previous feedback or guidance supplied by the on-line instructor, the instructor will refer back verbally to the previously supplied information. The reference will be concise, but detailed enough to prompt the student to remember the previous presentation.

The Instructor Model will be implemented as an accessible knowledge base to hold content and pedagogic items keyed by items that reside in the Student Model. These items include:

- Student learning style,
- Student expertise,
- Level student current KSAs (knowledge, skills, and abilities),

- Student personality attributes and attitude,
- Student fatigue and stress level,
- Student demographics,
- Instructor presentation style,
- Exercise type
- Interactions of the above factors as can be supported by current theory and research in psychology.

These items are more fully described within the discussion of the Student Model.

Student Model

This aspect of the system will support two primary roles. First, it will include the dynamic model of the student's understanding of the task elements and task procedures, as the training exercise progresses. It will also contain data for each student that will be used to select and modify the specific exercises and feedback styles used by the Instructor Model. The student's conceptual model must include the mental model held by the student of the situation and environment, along with the learning styles previous training, etc.

In addition to the student mental model, the Student Model will house information that will constrain the form and content of the student model and will inform the Instructor Model as to the types of feedback and interaction styles that are appropriate to each specific student. This type of information will include current student: learning styles, expertise level, **KSAs** (knowledge, skills, and abilities), personality factors, attitude, fatigue and stress. Each of these factors is described below.

Learning Styles. Research suggests that there are individual cognitive processing differences among people with certain variations more identifiable than others. These are referred to frequently as "learning styles" (Silverman, 1995). Individuals have preferences for mode of presentation of information that seems to be tied to how fast they can process information presented within different modalities (Just & Carpenter, 1992). The learning styles that the system will support will include:

- **Auditory processor**: An auditory learner needs to have information presented step by step, sequentially, via the auditory mode. This means that the Instructor Model must have tasks broken into steps for presentation and assessment
- **Visual-spatial processor**: A visual-spatial learner frequently thinks pictorially and processes visual material more quickly that auditory material. Task needs to be presented initially visually as a whole, with auditory back up. Feedback and preview steps need to be visually presented.
- **Kinesthetic processor**: A kinesthetic learner needs to have device controls that supply appropriate feedback/resistance as he/she learns to perform the task. The current Intelligent Flight Trainer (IFT) does this to a certain extent.

The system will need to have knowledge available concerning each student's preferred method of learning. To ascertain the student's preference beforehand, the student will enter answers to a series of yes-no questions presented on the exercise control (data entry) screen. These questions will query the student in a straightforward way as to how he or she has best learned different types of material and tasks in the past. This information will be used by the Instructor Model to select the best methods for guiding and supporting the student.

Student expertise level. Within the range of students in the course, expertise level consist of an indication of where within the training program the student is and the training objectives he or she has already met. This is information that will be entered by training personnel via the training manager or recorded from previous automatic instruction.

Student KSAs. The student's KSAs actually are incorporated in multiple aspects of the Student Model and thus are described elsewhere. However, for each student the KSAs will be:

- Knowledge items as reflected by the student mental model
- Skills as reflected by current performance data
- Abilities as reflected in performance on components of selection tests

Student Personality Factors. Aspects of a student's personality will in all likelihood impact their ability to learn the presented tasks (Tannenbaum, et. al., 1991). If the system can take such personality factors into account during presentation and remediation and modify its response in relation to those factors, it may lead to more effective training. Including this capability in the system will allow researchers to investigate the impact of personality variables on learning. Thus the initial set of variables could include:

- Extravert/introvert
- Thoughtful/Impulsive
- Analytic/Intuitive

Information concerning these variables would be derived from student performance on standardized personality tests Training staff or researchers would enter these data via the Training Manager function.

Student Attitude. According to experienced instructor pilots, the attitude of the student can be an important factor in how quickly helicopter flight tasks can be learned. This finding is supported in the literature (see for example, Noe, 1986). Attitude can be potentially broken into multiple factors, each of which could have some impact on training. The components that could impact learning include:

- Passive and not taking initiative ←→ Aggressive and overly-confident
- Responsive to direction ←→ Recalcitrant to direction

Information concerning a student's attitude would be based on instructor observation and entered into the system via the Training Manager.

Student Fatigue. Physical fatigue and sleep deprivation can have a negative impact on cognitive functioning (Orasansu & Backer, 1996). Therefore the system will ascertain the mental fatigue level of the student before he or she begins an exercise. The system will then adjust the problem difficulty to allow for the expectation of potential cognitive overload. To determine the level of fatigue, the student will be queried as to the number of hours of sleep the student had the previous night before he or she begins the exercise.

Psychological Stress. Psychological stress, resulting from various factors, has been shown to have a detrimental impact on cognitive processing, once it reaches a non-optimal level of arousal (Wickens, et al., 1991; Stokes & Kite, 1994; Hockey, 1986). The major negative impact is " "tunneling." Tunneling affects perception, cognition and decision making (Wickens, et al, 1991). Its impact is that an individual under stress will attend to fewer aspects of his or her environment, resulting in a more restricted awareness of the current situation. Additionally, an individual under stress will be less likely to arrive at novel or rarely used interpretations in the current situation. Finally, stress can cause the individual to focus on a limited number of task items. In other words the working memory is degraded under stressful conditions. According to instructor pilots, when students are initially learning helicopter flight tasks, they become overwhelmed by the task and their levels of arousal and stress increase. This results in a lessening of situation awareness and an over-focus on the current guidance supplied by the instructor. A final impact of psychological stress is to cause a strategic shift in which speed is accentuated over accuracy of performance (Hockey, 1986).

The adaptive learning system will gather and track data concerning the student's level of stress. Stress levels will be assessed by capturing speech input at the beginning of the task, and at points during the task. Stress indicators such as changes in speech rate and decibel and frequency levels will be calculated. Once a specified level of change has occurred, thus indicating that the student has potentially reached point of stress that is detrimental to the continuation of the task, the system will stop the current exercise, supply feedback to the student appropriate to the student's current performance and assumed mental model. Then the system will present a somewhat easier scenario to the student.

Training Analyst

The training analyst function collects student performance data so that the Student Model can be updated to reflect the most current high-probability model of the student. Collected data will include both physical and verbal responses by the student to the current task requirements and external information. The Training Analyst will contain performance indicators that will show when the student should restart the exercise. There will be multiple indicators for any particular exercise, with the specific indicator to be selected based on the student's current expertise level, at a minimum.

The Training Analyst will also contain algorithms for computing performance statistics within an individual's performance and across individuals, and tied to any specified training component or pedagogic technique. This will permit the training analyst to provide feedback to the Instructor Model. Time spent on each training element necessary to meet a training objective can also be calculated in order to assess the training efficiency of the system as it relates to the effectiveness of the various included pedagogic methodologies

Training Manager

The Training Management Function will allow human input of student background information, scenario elements, and training objectives for program, and will present results of analyses to training personnel and researchers. Given that the proposed system is both a training and a research tool, it is important to allow appropriate personnel access to databases internal to the system for updating and modification. Scenario generation is closely tied to the host simulator and the facilities will have to be analyzed to determine the required modifications or enhancements.

Presentation Manager

The Presentation Manager will receive input from the Instructor and Student Models and content information to select and present the material most appropriate to the current student in the most appropriate format and style. There are certain established parameters to the Presentation Manager, however. The overall system is scenario and simulator-based, with supplemental guidance and instruction. Therefore the presentation must stay within the constraints established by such a system. The visual elements of the presentation will contain simulated external and internal environments need to fly a given helicopter for the selected training maneuvers. Additional visual presentations may include displays that overlay the primary displays in order to supply cueing information to the student. There will also be an auditory component to the presentation. The system will speak to the student as described elsewhere, supplying task guidance, cueing, and feedback. The system will also ask probe questions as a data gathering mechanism, the results of which will be input into the Training Analyst and the Instructor Model.

Section

3

Summary

Final Summation and Key Comments on the Design

Summary

The purpose of this study was to develop an approach to a versatile adaptive system with growth potential to a learning instructional system. This study has developed a model set illustrating how a single knowledge representation technique can be used to capture mental models, actual situations and actual behavior. The common representation of conceptual graphs gives us enormous power and potential to manipulate, analyze and exchange all these kinds of knowledge within one framework. We have introduced an approach to determining how correct behavior can be distinguished from incorrect behavior, and how feedback on the incorrect behavior can be used to trigger further adaptation in the instruction sequence.

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Appendix

A

Conceptual Model Demonstration

Task Notes

Conceptual Modeling

Potential Training Task for Student

Current Situation at Start of Task

AC in air at elevation of 45', air speed of 90 knots/hr, movement in forward direction, no wind; there is a hangar 1200' south from the staging area and on the right; there is a water tower west of the hangar.

Task

1) Fly south from staging area 1200'.

2) Turn right (West) 90 degrees when parallel to the hangar.

3) Change elevation to 70'

4) Change air speed to 120 knots/hour.

5) Fly over the hangar toward the water tower.

There are several reasons for suggesting this task. First, it requires the student to use external visual cues that are somewhat distant while performing the task. We can discuss in our presentation ways to track eye movements to determine if the student monitors these cues or not. If not, we can assume that for our dynamic cognitive model of the student the relative location information supplied by the cues is not available. Second, student pilots often don't realize when to use the pedals for turning versus the cyclic, (at low elevations the pedals are used). If we have our hypothetical student have this as part of the task will allow us to demonstrate an observable that would indicate an aspect of the student's mental model. Third, since student pilots initially do not understand the relationship of the collective and cyclic with regard to pitch control, having the student change air speed will require him/her to integrate the use of both controls to ensure level flight. If we observe tipping forward, we can assume that the student's mental model does not have a correct representation of the collective-cyclic relationship. We can then posit potential representations that the student does have, based on a Bayesian analysis of his/her performance on other parts of this task or on subsequent tasks. Potential representations could include: 1) the student thinks that the collective has throttle function only (very common representation in novices), or 2) the student underestimates impact of the collective on the angle of attack of the rotor (a more sophisticated representation).

Student Profile

For our example student (first 5 items need to be pre-loaded into trainee database)

- Experience level: has never been to flight line, has had three days of core curriculum
- Demographics: 24 year old male from Pittsburgh, PA
- Cognitive strengths (from screening tests): strongly visual-spatial
- Cognitive weaknesses (from screening tests): low on auditory processing
- Attitude (from personality screening tests/instructor assessment): Over-reactive/nervous
- Fatigue level: low

Student Knowledge when starting the exercise (this information can either be assumed or be determined via on-line testing; either way, we should assign a probability value of having these pieces of information available to working memory at the start of the exercise):

- Control names
- Control functions, in general
- Instrument names and functions
- Distance from staging area to hangar

The following groupings represent the student's potential knowledge state as the exercise begins (note that this information is not in conceptual graph format, but I think the information to begin building such representations is there). However, since the student is very inexperienced, some of this information may not be in working memory at the start of the exercise. It should be retrievable from long term memory or easily updated if the planned actions are followed. Each item's availability should have an associated probability of being in working memory and a probability of being available to working memory (e.g., exists in long term memory). For any specific student model, these probabilities will be varied based on assessed background knowledge and personality factors. Later in the training exercise, the probabilities will be modified based on past experiences within the current simulation situation or previous simulator sessions. (In other words, there will be a cumulative, dynamic student model maintained by the system for each student who uses it.)

CONTROLS KNOWLEDGE

1) Collective: function is like throttle; it increases air speed

2) Cyclic: functions to control pitch

3) Pedals, functions to off-set torque

INSTRUMENT FUNCTIONS AND CURRENT STATES

1) Air speed indicator: indicates speed, currently at 90 knots/hr

2) Turn & Slip indicator: indicates relative positions of pedals, currently right pedal depressed enough to prevent torque

3) Vertical speed indicator: indicates how fast AC is rising, currently 0

4) Attitude indicator: indicates AC attitude with respect to the level, currently AC is level

5) (and with some AC—altimeter: indicates height above sea level)

STATE OF EXTERNAL CUES

1) Current AC position with respect to: front far view scanning ahead: runway, front near view: staging area, right far view: right close view: staging area lines

2) Position changes based on: texture gradient change, enlargement of selected location cueing objects, speed of closure

CURRENT ACTIONS

1) Maintaining positions of controls

2) Monitoring far cues

3) Monitoring near cues

4) Attending to training direction

PLANNED ACTIONS (this is the amount of direction that the system gives the student initially)

1) Fly straight at current elevation

2) Fly straight south for 1200'

3) Look for hangar

KINESTHETIC CONTROL RESPONSE EXPECTATIONS

1) <no current expectations>

Other Impacts to the Model Contents

There are other aspects of the student pertaining to the student model that aren't directly components of the model, but do impact the probabilities of informational or task planning and task action components entering or leaving the model while the student is performing the task. These are some of the student's personality characteristics, sociological background, and cognitive processing strengths and weaknesses. The characteristics that will impact the probabilities, and their impact, are:

Experience—As experience increases the likelihood that a new piece of information related to previously learned knowledge will be integrated will increase. Also, as experience increases greater amounts of information related to previously understood information will be learned more quickly.

Fatigue level—As fatigue level goes up, the probability of new information being learned or previously learned information being available decreases. Additionally, the likelihood that certain tasks such as monitoring, will be correctly performed decreases. The likelihood that only near cues or centered cues will be monitored over other cues will increase.

Affect type—As the anxiety level of the student increases, the probability of new information or plans entering the mental model decreases. The probability of monitoring only close informational cues such as instruments or close visuals will increase. The probability of over-focus on the most recent correction by the instructor will increase.

Learning style/cognitive strengths—Visual learners will have a higher probability of acquiring visually available information or retrieving from long term memory that has been presented visually, than of receiving or retrieving auditory-based or kinesthetically-based processed information. The same for all other preferred learning styles, in that they have a higher probability of receipt and use of information within their preferred modality.

Attitude—The student's attitude can negatively or positively impact his/her ability to learn information that is presented. A negative attitude will lessen the likelihood that information will be acquired and used. A positive attitude may increase the probability of an element entering the student's mental model.

Impacting Simulation Factors

There will be certain aspects of the simulated flight situation that will impact the student model, and will interact with the above factors, include:

Total amount of information to be processed during any instance of the simulation and the task to be performed—As the number of informational items to be attended to and task steps to be performed or planned for simultaneously increases, the probability of any specific plan or information item be attended to will decrease. As expertise increases, the probability of managing multiple simultaneous information items and plans to be executed will increase.

Total amount of information coming to any one sensory channel—As the amount of information to a specific channel increases, so does the processing load for the channel. As load increases, the likelihood that any specific information in the channel will be received, or if received, attended to or used, decreases. If redundant information comes via multiple channels, the probability of information receipt and/or use increases.

Note that to a large extent the simulation-based factors can be controlled by the instructor model used to select tasks for the student.

Impacting Pedagogic Factors

The use of specific pedagogic methods will increase or decrease the probabilities associated with whether or not a particular student given a specific training situation will modify his/her mental model and responses in a certain way. These factors include:

Specific task selection—To ensure that the student's mental model will have the greatest probability of changing correctly, the instructor model will need to select tasks based on an assessment of the current student model as compared to overall learning goals that have been established for this level of the curriculum. For example, if the student does not understand the pitch control aspect of the collective, then the task should require the student to practice using the collective and the cyclic in concert to control the pitch. Task selection should also contain identifiable points for gathering observable data in order to update the student mental model or potential models.

Rate of task content presentation/Task step previewing—To increase the probability of correct performance, as a default presentation method for most students, the instructor model should first describe the whole task, then as each step is to be performed. The "instructor" should state the step. The detail level of the step should be finer grained for more novice students. This will mean that very novice students will be receiving constant task guidance. Students who have shown proficiency on specific aspects of the tasks should receive less-detailed preview.

Style of verbal presentation—To increase the probability of information being added to the student's mental model, the verbal presentation style of the "tutor" should be compatible with certain aspects of the student. For example, if the student is from the South, speech presentation should be slower than for northern students. Also, more highly anxious students, as reflected on personality portions of screening tests, should receive more detailed task guidance and more frequent positive feedback than the average student. Belligerent/arrogant students should receive terse guidance.

Task aiding—If the pedagogic module supplies task aiding such as highlighting important sources of information, and does so in a way that makes use of the student's learning style, the probability of acquiring the information will increase.

Feedback style—The style and frequency in which the pedagogic component supplies feedback should be based on student attitude and learning style. Content should be based on student performance or assumed most probable current mental model.

Example Operation

Student Mental Model During Step 1 of Task

The student begins the task with the previously described mental model.

The instructor model says: "Fly south 1200'. Maintain elevation and speed"

Student looks at his controls (observed by system via gaze or head movement detector).

Student looks out window to distant end of runway (observed via gaze or head movement detector).

The student may demonstrate certain behaviors at this point. He/she may:

Maintain all controls in the same positions as they were placed at the beginning of the exercise, thus maintaining course, speed and elevation.

Move one or more of the controls (data captured by the system, either based on detection of control changes or AC changes).

If the situation is the first case, then we can assume that the section of the student's mental model concerning the kinesthetic response expectations of the controls has been immediately filled correctly, at least temporarily.

If the student doesn't not maintain all controls in their initial positions, then kinesthetic response expectations of the controls portion of the student model will be updated, based on the control that has been moved. Given the size of impact on the AC of movement of any control, the tolerance level should be very low before the model is updated and the Instructor model offers feedback. Actually, one can expect that a beginning pilot will have difficulty maintaining the controls in their original position, so each time the controls go out of position, the Instructor model should indicate immediately which control needs adjustment, and subsequently which other controls need further position modification. (Please note that our hypothetical student will also require frequent positive feedback statements as his model changes to reflect learning of the task.)

Once the student has flown most of the 1200', we assume the cognitive model at this point is:

CONTROLS KNOWLEDGE

1) Collective: function is like throttle; it increases air speed

2) Cyclic: functions to control pitch

3) Pedals, functions to off-set torque

INSTRUMENT FUNCTIONS AND CURRENT STATES

1) Air speed indicator: indicates speed, currently at 90 knots/hr

2) Turn & Slip indicator: indicates relative positions of pedals, currently right pedal depressed enough to prevent torque

3) Vertical speed indicator: indicates how fast AC is rising, currently 0

4) Attitude indicator: indicates AC attitude with respect to the level, currently AC is level

5) (and with some AC—altimeter: indicates height above sea level)

STATE OF EXTERNAL CUES

1) Current AC position with respect to: front far view scanning ahead: runway, front near view

2) Position changes: far end of runway approaching (speed of closure)

CURRENT ACTIONS

1) Maintaining positions of controls

2) Monitoring far cues—end of runway

3) Monitoring near cues—staging area

4) Attending to training direction

PLANNED ACTIONS (this is the amount of direction that the system gives the student initially)

1) Fly straight at current elevation

2) Fly straight south for 1200'

KINESTHETIC CONTROL RESPONSE EXPECTATIONS

1) <contents based on student performance during previous portion of task, but for each control, it will be in the form of "X size change of control equals X size change of AC performance">

At this point the student receives new input from the instructor model. "Turn due west at the hangar." There are several behavioral possibilities after this direction. The student may:

- Fly past the hangar and never turns.
- Turn west, but not due west.
- Use the cyclic to make turn rather than the right peddle.
- Both 2 and 3
- Turned at the proper location, but either late or early
- Crash into the ground
- Something else

Each of these behavioral possibilities can reflect multiple possible mental models. For example, if the student flies past the hangar, he/she could have:

Not monitored out the front and right windows for the hangar. This possibility may be supported or ruled out by eye or gaze tracking, or

Not remembered how or which controls to use to make a turn. This possibility may be supported by data gathered from control actuation.

If the student's mental model indicated that the student had not attended to external cues, the system would stop the scenario, and point out the needed cue both verbally and visually. The visual indicator would be a box surrounding the cue of importance. After the intervention, the training session would restart.

In the case of second behavioral possibility, "Turn west, but not due west," the following are possible reasons for the error in performance. The student:

- Did not understand the concept of "due west," or
- Over or under used controls while making turn. This possibility may be supported or ruled out by data gathered form control actuation.

If the system determined that the student did not understand the concept of "due west," the simulation would be stopped and the term explained. If the system determined over or under use of a control, the system would stop the simulation and would stress the need to make small changes, possibly with an exercise on control moderation. The style of the feedback would match the student's learning style. After the intervention, the training session would restart.

For the third behavioral possibility, "cyclic used for turn, not peddle," control use data would indicate if this were the case. If so, the mental model might reflect one of four possibilities. The student might think:

1) The cyclic is always used for turning.

2) The cyclic is used for turning for any elevation over X number of feet (with X being less than the current elevation of the AC).

3) The pedals are used only for anti-torquing.

Both 1 and 3

However, determination of the exact student model for this type of error is not really necessary. Another option is to have the instructor module not gather more information at this time, but to explain the rule concerning pedal use for turning at elevations lower than 50'. The student model would be updated to reflect a correct understanding of the relationship, after the intervention. The student would begin the simulation again.

In the event that during a run of the simulation subsequent to the first instructor intervention, the student errs on this step of the task, the instructor model should collect more data to determine the exact problem with the student model. This can be done in either of two ways. The instructor model could present the student with either: 1) two multiple choice questions about cyclic and peddle use (this means having pre-developed questions), or 2) a new simulation task in which the student must make a turn at an even lower.

Example Adaptive Instruction

This section gives a brief example showing how conceptual graphs can represent the knowledge required to perform adaptive instruction within the simulated training environment. We will show a simple two-step task, where the student performs the first step correctly, then the second step incorrectly. The terms **expected** and **assumed** mean things that are in the system preflight. The terms **observed** and **actual** are things that occur during the simulation.

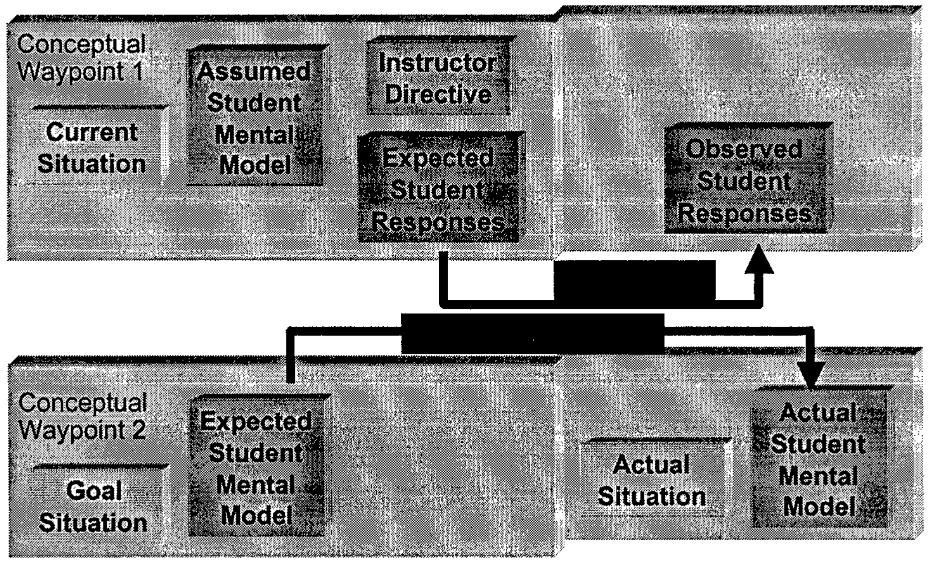

Figure A-1 Waypoint sequences

The process consists of a sequence of conceptual waypoints, where each waypoint represents a step in the instructional process. Linking these waypoints together, we can establish a single "lesson" of instruction.

Example Task

You are heading south at 45 ft altitude. When you reach the hangar, turn right and ascend to 120 ft.

We will present two conceptual waypoints in this task. The waypoints correspond roughly to the stages of the task: ***turn right,*** and ***ascend***.

Waypoint A

For simplicity, we propose a session where the aircraft is already moving. Future work will address the issues of the student's maintaining a set course and speed. The waypoint is the point at which the instructor unit issues a directive.

Current situation - Waypoint A

The current situation at the start of the training session is pre-defined as shown in Figure 1. The aircraft's movement is a velocity whose heading is 180 degrees and whose airspeed is 70 knots. The aircraft's location is a place with height 45 ft and coordinates. There is a hangar at a place *h* and a water tower at a place *w*.

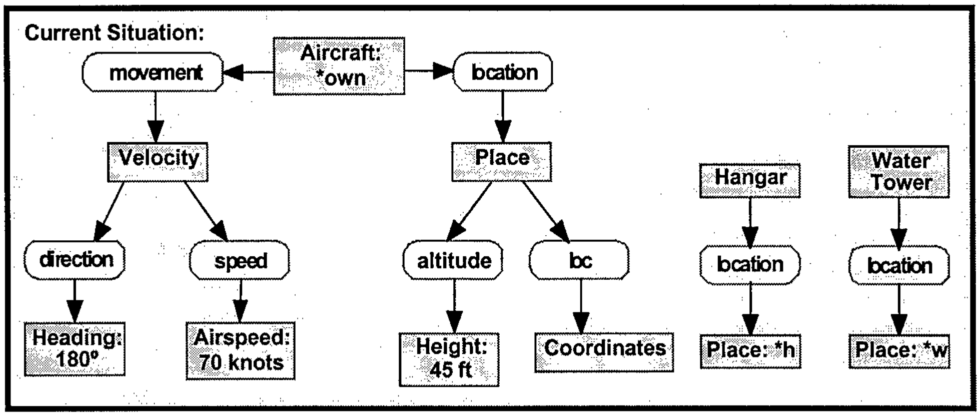

Figure A-2 Assumed mental model - waypoint A

Note that the student should think (among other things) that the cyclic controls the pitch, and the collective controls the altitude and velocity.

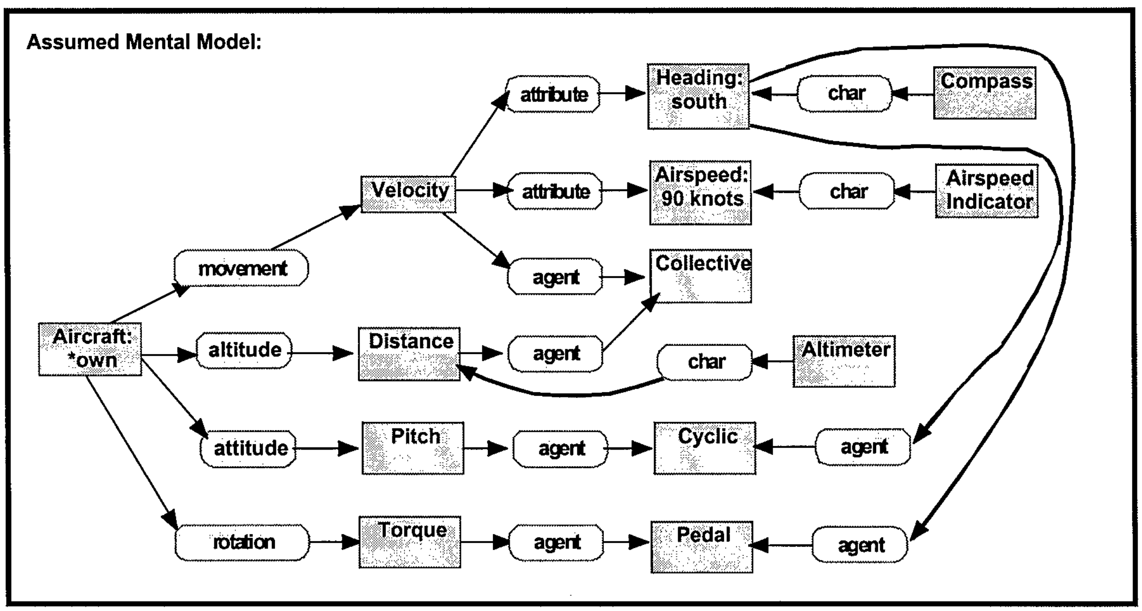

Figure A-3 Planned instructor's direction to student - waypoint A

The instructor unit gives the student a direction: Cause the aircraft to have a direction of **west** at the hangar. This graph is somewhat simplified for the purposes of this illustration.

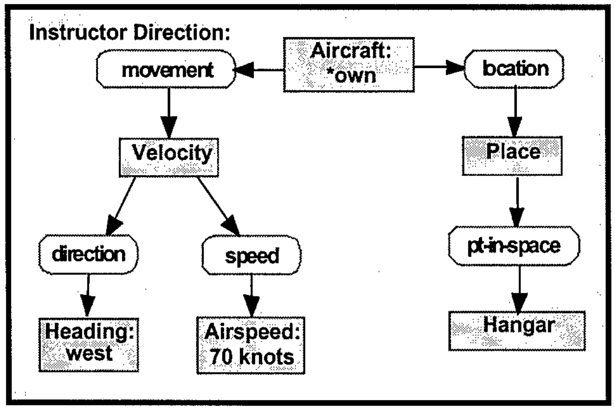

Figure A-4 Expected student behavior - waypoint A

The expected student behavior is to move the cyclic to the right.

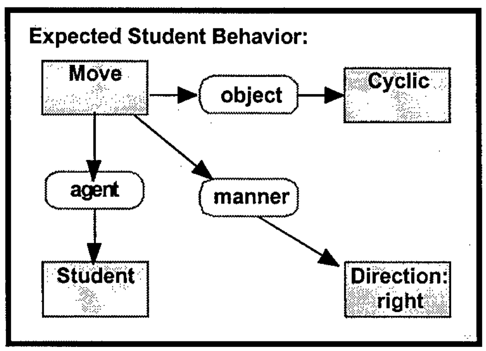

Figure A-5 Expected resulting situation - waypoint A

If the student performs the correct behavior, the aircraft will now be headed west, with all other attributes the same.

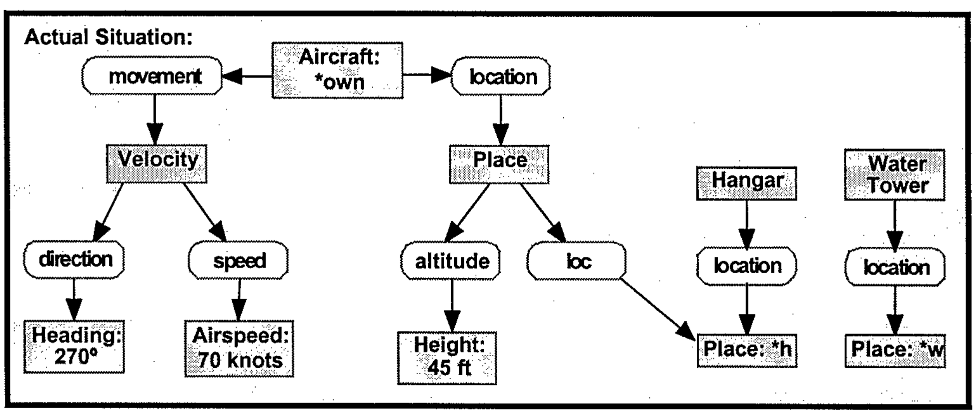

Figure A-6 Observed student behavior - waypoint A

In this environment, we have access to the details of a student's actions. We suppose in this example the following observations:

- Student moved the cyclic to the right

- Student moved a pedal.

Actors linked to the simulator will allow us to determine what controls were activated, resulting in the graph below.

For future work, we will be able to observe other behaviors. For this example, let us suppose that we also observe the following:

- Student makes eye contact with the compass for 500 msec

- Student makes eye contact with the airspeed indicator for 300 msec.

Elements of cognitive theory allow us to assume that these readings have now entered the student's working memory. We intend to model these observations in the future.

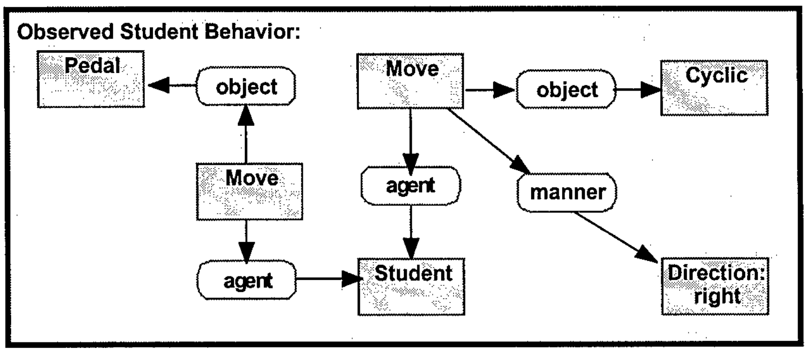

Figure A-7 Expected situation - waypoint A

After performing the instructor's directive, the aircraft should be heading west and located at the hangar.

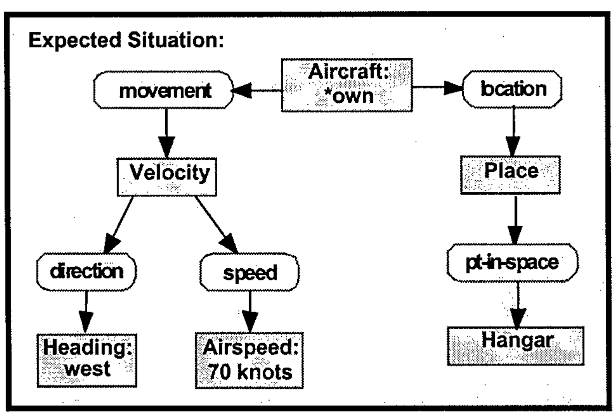

Figure A-8 Inferred mental model - waypoint A

Although the purpose and actions of the collective may be in the student's actual mental model, we have no means of directly knowing that, since the student did not activate the collective during this observation. We therefore infer that the student knows the cyclic controls the heading and pitch and the pedal controls the heading.

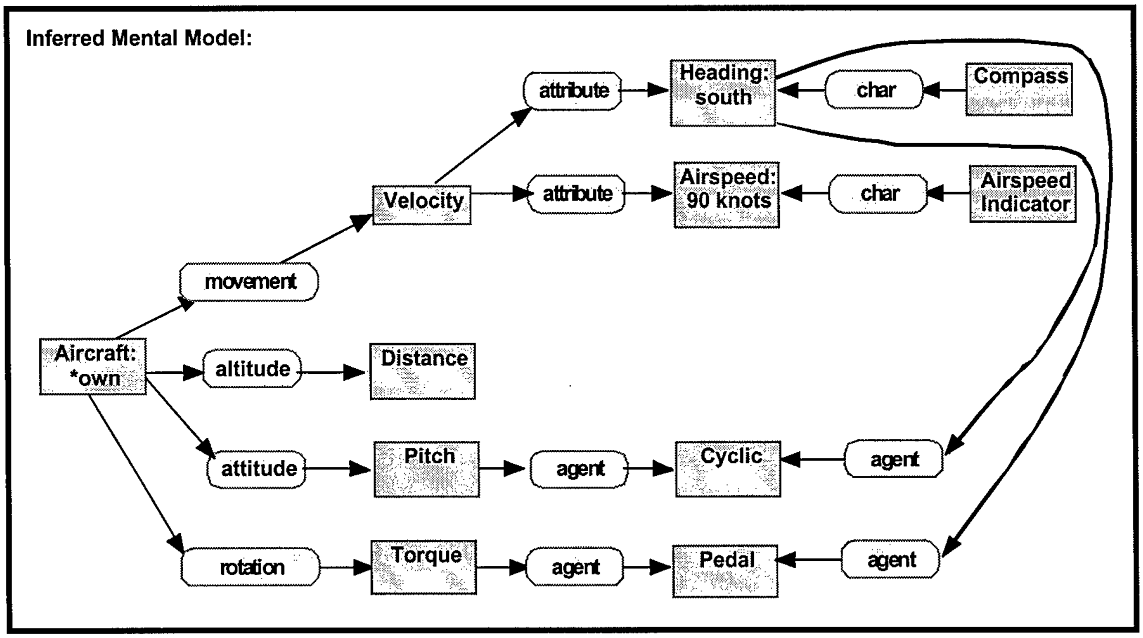

Figure A-9 Processing

We have three means of evaluating progress from one waypoint to another:

- Compare the actual (simulated) situation with the expected situation.
- Compare the student's observed behavior with the expected behavior.
- Compare the student's inferred mental model with the expected mental model.

In waypoint A of this example,

- the actual situation matches the expected situation,
- the observed behavior includes the expected behavior (without conflicts) and
- the student's inferred mental model is included in the expected mental model (i.e., we have not inferred anything that should not be in the expected model).

We can therefore reasonably conclude that the task was performed correctly and that the mental model is compatible with what we expect it to be. No adaptation is required.

Waypoint B

We now consider the second waypoint, after the student has successfully turned to the west. The instructor directs the student to ascend to 120ft. (We assume the intent is to maintain course and speed.)

Current situation - Waypoint B

Note that the actual situation reflects that the aircraft is now heading west and is located at the hangar.

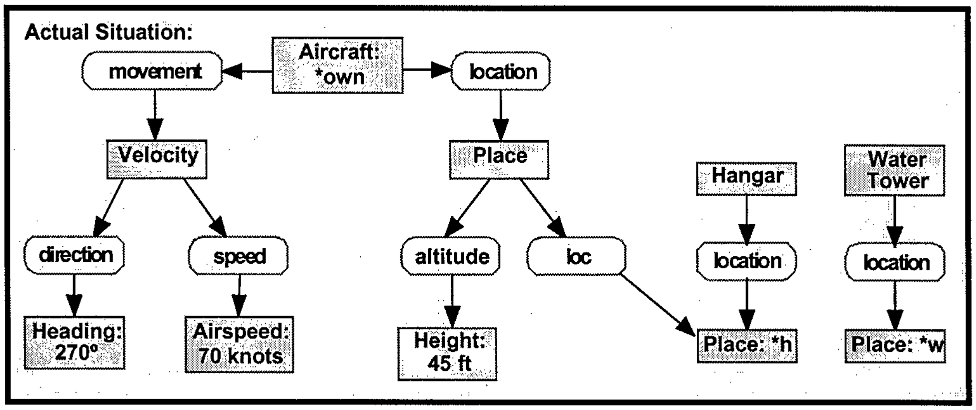

Figure A-10 Assumed mental model - waypoint B

Same as for Waypoint A, since we've detected no differences in expected behavior. In future work, we will be able to increase the confidence level for the relations involving the cyclic and pedal, since the student did operate those controls correctly.

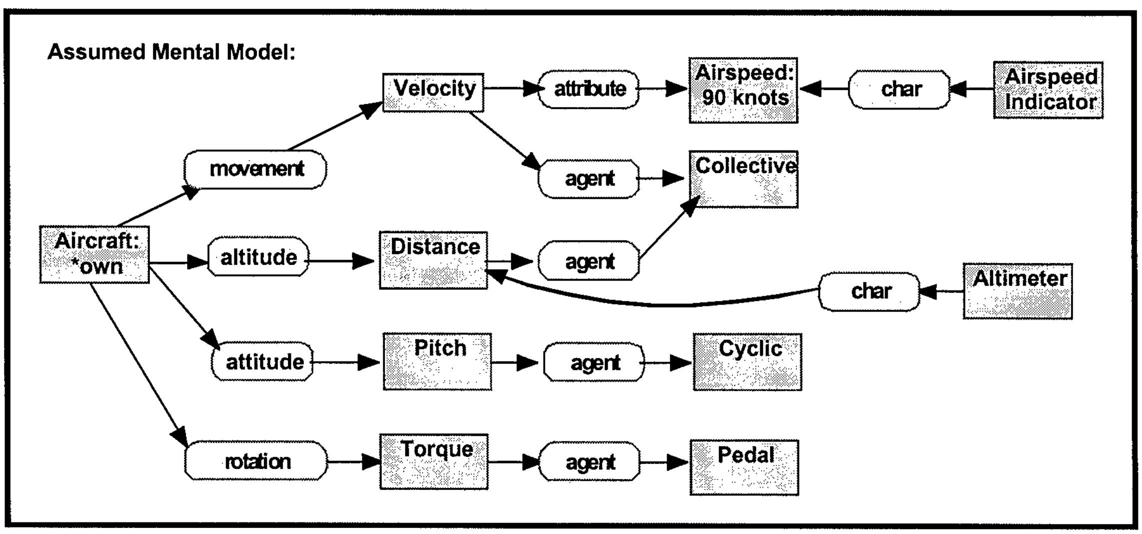

Figure A-11 Planned instructor's direction to student - waypoint B

The instructor now directs the student to cause the aircraft to have an altitude of 120ft.

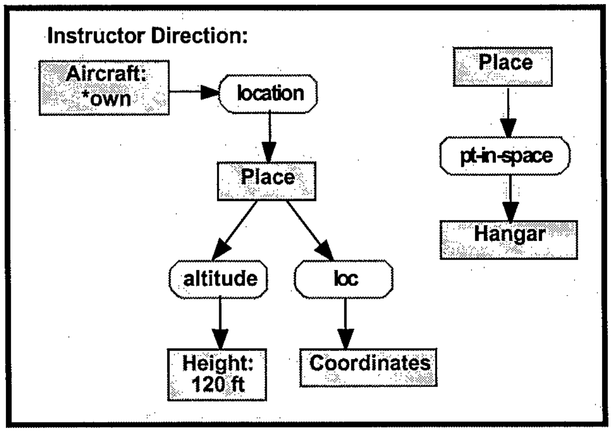

Figure A-12 Expected student behavior - waypoint B

In response to the instructor's directive, the student is expected to lift and rotate the collective, to gain altitude without losing speed.

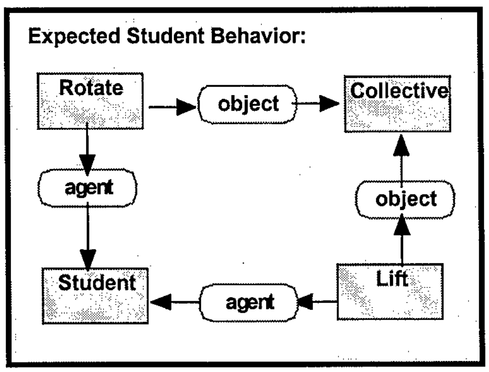

Figure A-13 Expected resulting situation - waypoint B

After performing this directive, the aircraft should be heading due west at an altitude of 120ft.

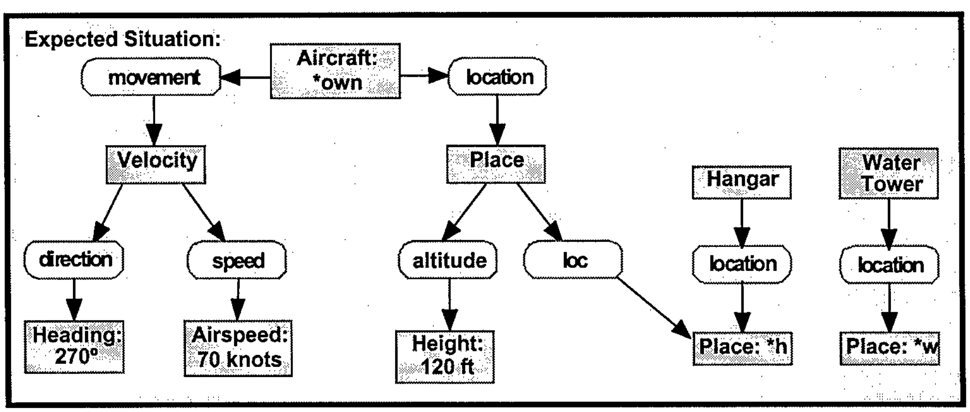

Figure A-14 Observed student behavior - waypoint B

We make the following observations of the student's behavior.

- The student moved the cyclic back.

■ The student observed the altimeter for 1200 msec.

Since the student was expected to use the collective, this should lead to our system detecting a problem. We'll show that below.

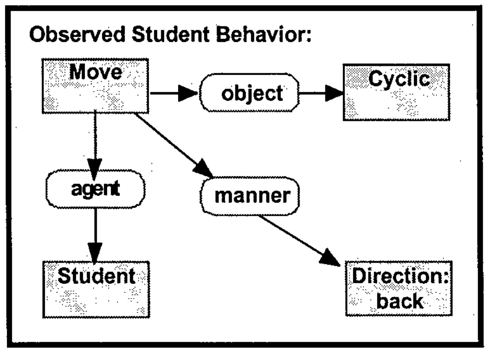

Figure A-15 Inferred mental model - waypoint B

Now that the student has been observed using the cyclic to affect altitude, we can infer that the student's mental model shows the cyclic as the agent of the altitude, as shown below. The altimeter is shown here because the student looked at it.

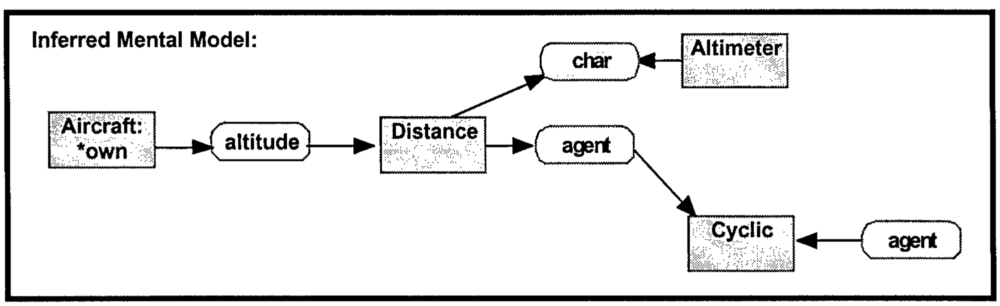

Figure A-16 Processing

Again using these three means of evaluating progress:

- Compare the actual (simulated) situation with the expected situation.
- Compare the student's observed behavior with the expected behavior.
- Compare the student's inferred mental model with the expected mental model.

In this example,

- the actual situation may match the expected situation. In this case we assume no change in flight parameters.
- the observed behavior does not match or include the expected behavior
- the student's inferred mental model does not match or include the expected mental model.

We can therefore reasonably conclude that the task was performed incorrectly. Furthermore, we can reasonably determine what student misconception caused the incorrect behavior. We will now briefly discuss how the system can adapt to this student.

Adaptation

After the two steps have been performed, we can infer the following graph as the student's mental model. The student actually believed that the cyclic controlled both altitude and pitch. Figure 16 shows what the system can infer about the student's "actual" mental model. Note the grayed portion indicating the mismatch:

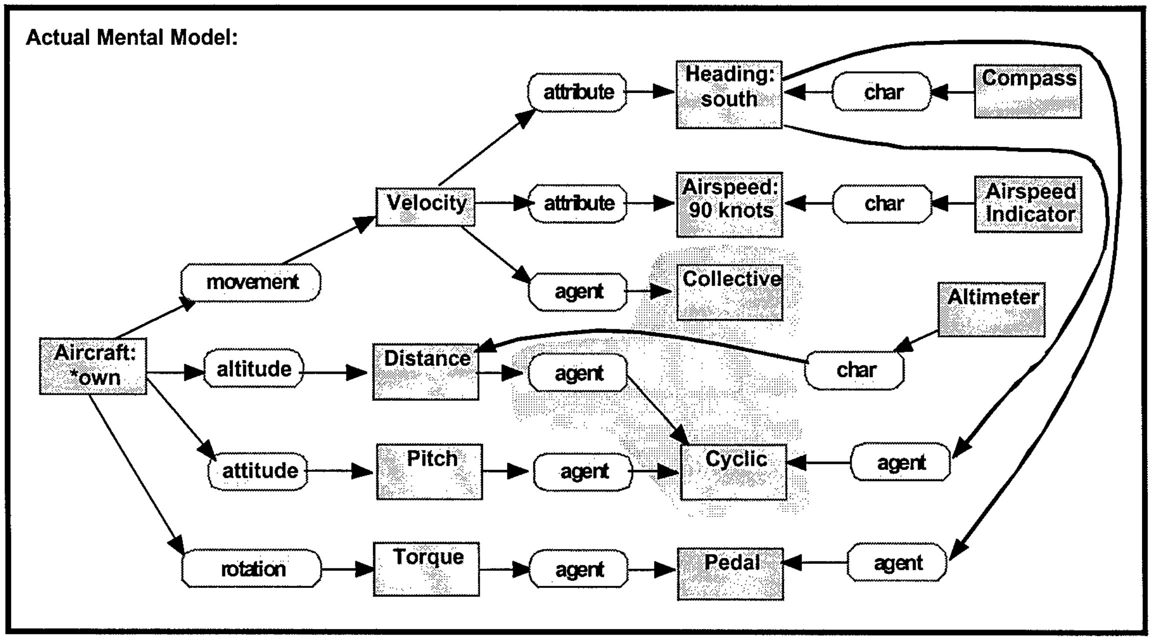

Figure A-17 Adaptation

Not only can graph operations provide a reasonable "best match" for analysis purposes, we can also use the "difference" between two graphs to our benefit. For instance, a comparison of the expected mental model and the actual mental model reveals that they almost match, with the exception of the shaded portion shown in this model.

Adaptation of the instruction is therefore required, at this point, for two purposes:

- address the misconception that the cyclic controls altitude
- distinguish between the operation of the cyclic and the collective.

The system administration module(s) would identify previous lessons on the operation of the cyclic and operations of the cyclic vs. the collective and switch to those lessons.

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